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New records and geographic distribution map of *Proceratophrys sanctaritae* Cruz & Napoli, 2010 (Anura, Odontophrynidae)

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Abstract

Until now, *Proceratophrys sanctaritae* Cruz & Napoli, 2010 has only been known from its type locality, Serra do Timbó, municipality of Amargosa, Bahia, Brazil. Due to its restricted geographic range, this species is considered Critically Endangered. We report new records of *P. sanctaritae* in Bahia and update its geographic distribution. Although the geographic range of *P. sanctaritae* is significantly expanded with our new data, the mountainous forest habitat of this species is highly susceptible to human modification, and *P. sanctaritae* is still likely threatened under IUCN criteria.

Keywords

Atlantic Forest, Caatinga, conservation, horned frogs, transitional areas

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Introduction

Proceratophrys Miranda-Ribeiro, 1920 is the most species-rich genus of the family Odontophrynidae, with 43 species distributed throughout the Neotropics (Frost 2022). Popularly known as horned frogs, these organisms are found in leaf litter near lotic environments, where their cryptic color pattern makes it difficult to distinguish them (Prado and Pombal 2008).

The taxonomy of *Proceratophrys* is mostly based on morphology, with eyelid and rostral appendages essential in defining species groups in the genus. For example, the *P. appendiculata* group, to which *P. sanctaritae* Cruz & Napoli, 2010 belongs, is characterized by eyelid appendages and a triangular rostral appendix (Prado and Pombal 2008). Nevertheless, a recent analysis does not support the monophyly proposed for most of the species in the group (Dias et al. 2013). Additional phylogenetic studies, including a larger data set, is necessary to elucidate the evolutionary relationships among *Proceratophrys* species (Santana et al. 2021).

Proceratophrys sanctaritae (Fig. 1) is a medium-sized

Figure 1. *Proceratophrys sanctaritae* from Amargosa municipality, Bahia, Brazil.

frog (mean male snout–vent length (SVL) = 41.0 mm) that is endemic to the Atlantic Forest in Brazil (Cruz and Napoli 2010). Until 2018, it was known only from its type locality, Floresta Santa Rita (13°04′S, 039°38′W) in the Serra do Timbó, Amargosa municipality, Bahia (Frost 2022). The Serra do Timbó is a mountain range characterized by a rugged relief, between 600 and 900 m a.s.l., and covered mainly by semideciduous tropical forest fragments (Cruz and Napoli 2010). Despite the humid tropical climate, the Serra do Timbó is in a transition zone between the Caatinga and Atlantic Forest morphoclimatic domains (Olson et al. 2001).

Proceratophrys sanctaritae was categorized as Critically Endangered, as it was only known from a single location under threat from habitat loss and degradation due to livestock and agriculture. Here, we provide new occurrence records that expand the species' geographic distribution to an ecotone region in south-central Bahia and elevational range.

Methods

Our new records were collected as part of anurofauna inventories conducted between 2017 and 2019 at two sites in Bahia: Morro do Mara and Wenceslau Guimarães State Ecological Station. Morro do Mara (MM; altitude = 560–960 m) is a Seasonal Semideciduous Forest fragment in good preservation, with lentic and lotic water bodies, and surrounded by cattle pastures and cocoa plantations. The Wenceslau Guimarães State Ecological Station (WGSES; altitude = 440–900 m) is characterized by a Submountain Dense Ombrophilous Forest comprising well-preserved forested fragments surrounded by cattle pastures and cocoa plantations. WGSES is in the Central Atlantic Forest Corridor, an important conservation region with many endemic species and high biodiversity. At both sites, lakes, temporary and permanent ponds, streams, and the litter of trails near these water bodies were monitored.

Serra do Timbó, WGSES, and MM are hilltops in the transition between the Atlantic Forest and Caatinga, and the three sites are exposed to threats associated with human activities as agriculture expansion, pasturing livestock, and flooding behind dams. We collected our specimens of *P. sanctaritae* under SISBIO collection licenses #35068 and #18.660. Specimens were euthanized with an overdose of 5% lidocaine, fixed in 10% formalin, and stored in 70% alcohol. The specimens were deposited in the zoological collection of the Universidade Estadual do Sudoeste da Bahia (MHNJCH; Jequié, Bahia Brazil) and Zoological Museum of Universidade Estadual de Santa Cruz (MZUESC; Ilhéus, Bahia, Brazil).

The altimetry distribution map was built from elevation data available in the SRTM 90m DEM Digital Elevation Database on the CGIAR-CSI portal (https://srtm.csi.cgiar.org). The data present a 90 m resolution at the equator and is available in 5 × 5-degree grids. Data were obtained using the *raster* package v. 3.4.13 (Hijman 2021) and the map produced with packages *rgdal* v. 1.5.21 (Bivand et al. 2021), *sf* v. 1.0.2 (Pebesma 2018), *geobr* v. 1.6.4 (Pereira and Gonçalves 2021), and *ggplot2* v. 3.3.5. (Wickham 2016). The analysis was performed in R v. 4.1.2 (R Core Team 2021).

Results

***Proceratophrys sanctaritae* Cruz & Napoli, 2010**
Figure 1

Material examined. BRAZIL – **Bahia** • Jequié, Morro do Mara; 13°53′43.46″S, 039°57′21.64″W; 913 m a.s.l.; 29.VI.2018; APA leg.; 1 ♀, MHNJCH1561; • Jequié, Morro do Mara; 13°53′44.09″S, 039°57′20.90″W; 907 m a.s.l.; 30.VIII.2019, APA leg.; 1 ♂ MHNJCH1710; • Jequié, Morro do Mara; 13°53′44.07″S, 039°57′20.81″ W; 906 m a.s.l.; 07.XI.2020, DFOB leg; 1 ♂ MHNJCH1186 • Wenceslau Guimarães, Wenceslau Guimarães State Ecological Station; 13°35′69″S, 039°43′18″W; 700 m a.s.l.; 04.V.2018; MFVN leg.; 1 juvenile, MZUESC22133.

The Morro do Mara individuals were found at night in the highest parts of the mountain, where they were occupying leaf litter 1–20 m from lotic water bodies. The Wenceslau Guimarães individual was captured during the day (16:30 h) and was foraging in the leaf litter in a hillside forest.

Identification. *Proceratophrys sanctaritae* (Fig. 1) is a medium-sized frog presenting a broad and elongated zygomatic branch of the squamosal in sutural contact with the maxilla. This character attributes the species to the genus *Proceratophrys* (Cruz and Napoli 2010). We identified our specimens by their body size (adult males SVL 38.4–45.5 mm in *P. sanctaritae*; Cruz and Napoli 2010, and by the presence of a single long, unicuspidate palpebral appendix with a triangular rostral appendix, which distinguishes this species from others of the

genus that potentially may occur in the areas: *P. renalis* (Miranda-Ribeiro, 1920); *P. schirchii* (Miranda-Ribeiro, 1937), and *P. laticeps* Izecksohn & Peixoto, 1981). The SVL of our specimens ranged from 37.62 mm to 39.09 mm.

Our Moro do Mara and Wenceslau Guimarães records of *P. sanctaritae* are 95 km and 56 km, respectively, from the species' type locality (Fig. 2). The species' extent of occurrence is 613 km^2, formed by a polygon encompassing the three known occurrences; this area does not represent a prediction analysis of the species' distribution or a refined landscape ecology analysis, as ecological niche modeling has not been done. By including altimetry in the map, other locations in Bahia with conditions similar to those known for *P. sanctaritae* can be inferred as potential occurrence areas and providing a starting point for future surveys; these include the mountain chain that extends from Serra do Timbó to Candido Sales, peripheral to the Espinhaço Mountains (Fig. 2).

Discussion

Brazil sustains the greatest global amphibian diversity (Segalla et al. 2019). However, there is an alarming lack of information concerning the amphibians' occurrence in Bahia, which is highlighted by the frequent publication of notes on geographic distribution of amphibians in the state (Dias et al. 2010, 2011; Camurugi et al. 2010) and the large number of new species described in the last few years (Caramaschi et al. 2013; Dias et al. 2020; Novaes-e-Fagundes et al. 2021). The same pattern is observed throughout all of Brazil, and, according to Guerra (2020), 25% of the anuran species in Brazil have been described in the last 20 years.

The increase in the number of monitored areas in Bahia (Camurugi et al. 2010; Dias et al. 2014; Freitas et al. 2018; Bastos and Zina in press) can reduce the Wallacean deficit of species whose geographic distributions are still restricted to their type localities (Whittaker et al. 2005). For example, *Phasmahyla timbo* Cruz, Napoli

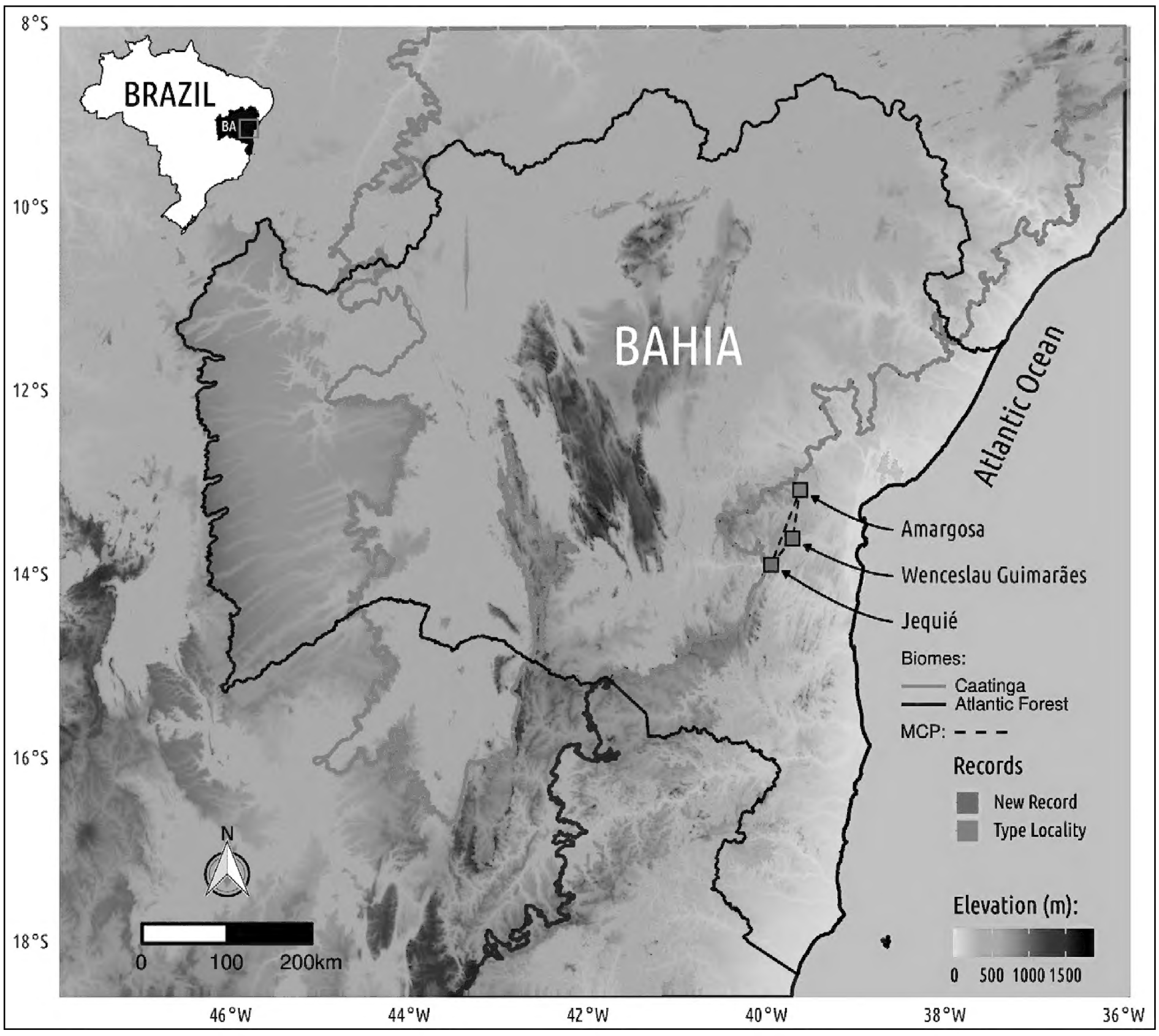

Figure 2. *Proceratophrys sanctaritae* distribution map in Bahia, Brazil, with boundaries between the Caatinga and Atlantic Forest biomes. Similar colors represent environments having similar altimetry. MCP (dashed line) = Extent of Occurrence). (Elevation data from SRTM 90 m DEM Digital Elevation Database).

& Fonseca, 2008 was only observed at its type locality at Serra do Timbó until found in 2007 and 2008 by Camurugi et al. (2010) at the Michelin Biological Reserve in Igrapiúna, Bahia. Another example is *P. sanctaritae*, the focus of this study. Known only by its type locality, it is classified in the Red Book of Brazilian Threatened Fauna (ICMBio 2018) as Critically Endangered. The species carries this status as its occurrence was, until now, restricted to approximately 8 km² in a severely fragmented region where, as of 2009, only 3% of native vegetation remains, but forest loss has continued in recent years (ICMBio 2018).

The increase of the known geographic distribution of *P. sanctaritae* results in an extent of occurrence less than 5,000 km² (Fig. 2), which implies that this species would better fit Endangered. The new area of occurrence is less than 500 km², and the number of locations are less than five (IUCN 2022). Additionally, all sites where the species is known to occurred are under threat by human activities, mainly from severe habitat loss caused by conversion of native forests towards crops and flooding caused by river damming.

Due to the difficult access and unsuitability for agricultural purposes, most forest remnants outside protected areas in central south Bahia are on slopes or mountain tops (Thomas et al. 1998, 2008). Amphibian diversity hotspots in Bahia's Atlantic Forest are generally associated with mountainous locations, such as Serra Bonita (Dias et al. 2014), Serra do Timbó (Freitas et al. 2019a), and Serra da Jibóia (Freitas et al. 2018). These sites present high rates of endemism and are important reservoirs of biological diversity. Anurans should be highlighted among this biological diversity, as they have unique ecological roles and show high rates of endemism in high-altitude environments.

The current distribution of *P. sanctaritae* is a high-altitude Atlantic Forest's remnant corridor in contact with the Caatinga (Fig. 2). Another frog species, *Bokermannohyla capra* Napoli & Pimenta, 2009, has the same restricted distribution, with isolated populations in high-altitude forest fragments. This similarity may be the effect of past events that resulted in a repeated pattern among frog species and even between higher taxa (Santos 2002; Carnaval et al. 2009, 2014; Freitas et al. 2019b; Menezes et al. 2020; Oliveira-Silva et al. 2021). As *P. sanctaritae* is known only from high altitudes, it can be used as a model for studies on the *P. appendiculata* group's phylogeographic history and to tell the history of the Atlantic Forest and northeastern transition areas.

Although we have not done ecological niche modeling, coincidences are seen between *P. sanctaritae* occurrences in altitude patches within the Atlantic Forest biome. The species may occur in other non-protected areas in a continuum of mountains. Unprotected mountainous areas are the sources of rivers and are often the only localities retaining moisture in an Atlantic Forest/Caatinga matrix. The future of the Atlantic Forest and Caatinga, and the species sheltered by these morphoclimatic domains, will depend on well-planned conservation strategies based on quality information of its remnants and including investigations of its faunal and floral richness and composition. Creation of new protected areas, restoration projects, and management of natural resources will be critical.

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Authors' Contributions

Conceptualization: JZ, APA. Formal analysis: DFOB, PBAJ. Investigation: DFOB, MFVN, APA. Methodology: MFVN, PBAJ, APA, DFOB. Validation: JZ. Visualization: IRRD. Writing – original draft: APA, JZ. Writing – review and editing: APA, DFOB, JZ, IRRD.

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